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THE NEW NMC MEDIUM RANGE FORECAST MODEL -- AN INTRODUCTORY NOTE

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MEDIUM-RANGE MODELING BRANCH

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1. Introduction

A new medium range, numerical weather prediction model was implemented at the U.S. National Meteorological Center (NMC) on April 17, 1985. This note provides a general introduction to the new model which is referred to as the MRF, or medium range forecast, model.

In the summer of 1983, NMC began to use its new supercomputer, a CYBER 205. By taking advantage of the computer's capabilities for very rapid processing of long data strings, or vectors, it was possible to increase the horizontal resolution of the NMC global spectral model from rhomboidal 30 to rhomboidal 40 spectral truncation. The provision to NMC of authorization to use highly optimized Fast Fourier Transforms developed by C. Temperton at the British Meteorological Office was instrumental in this stage of development.

Subsequent to the implementation of the rhomboidal-40 model, work was begun to augment the sophistication of the physics parameterizations used in the model. Extensive collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) accelerated this process. Concurrently, the model's vertical resolution was increased from 12 to 18 layers. By the Summer of 1984 a series of test integrations with the new model were undertaken at NMC. The success obtained, warranted an intensive daily comparison between the new model and the operational forecast model. A number of improvements were effected during the course of this experimental work. The last change, made in January 1985, involved the introduction of a "silhouette orography" following a suggestion of Fedor Mesinger. Comparative results for the new model and the operational model obtained during February and March 1985, a period during which both models remained invariant, are shown later on.

At the time of writing, the new model has been operational for just four months. We anticipate further development of the model to achieve greater efficiency of operation and increased accuracy of the forecasts. This presentation is limited to outlining the broad characteristics of the model and giving a preliminary assessment of its accuracy. A complete description of the mathematical and physical bases for the model will be prepared later.

2. General Characteristics of the MRF Model

The new medium-range forecast (MRF) model has been constructed on the foundation of the CYBER version of the NMC global spectral model. The basic design of that model has been described previously (Sela, 1982). In this section, we provide an overview of the changes that have been incorporated in the model which warrant its new appelation, MRF.

2.1 Vertical Structure - Topography

The vertical resolution of the MRF model is provided by 18 layers of equal increments of pressure normalized by the surface pressure, which is a function of horizontal position and time. The previous NMC model had 12 unequally spaced layers. The dominant spatial variation of surface pressure is related to the height of the model orography above mean sea level. The field of orography was defined to reflect the silhouette of the mountains covering each cell of the model's Gaussian grid. The new orography has appreciably higher elevations than were used in the previous model. An example of this contrast is shown in Figure 1.

2.2 Radiative Heat Transfer

The algorithms used for computing radiative heat transfer were provided by GFDL where they were developed by S. Fels and D. Schwarzkopf. Because these algorithms were designed for use with the GFDL eighteen layer model, which has unequal layer depths, it has been necessary to interpolate the MRF's dependent variables into the GFDL model coordinate system in order to use the algorithms. Conversely the radiative heating rates must be interpolated from the GFDL model's vertical coordinate into the MRF coordinate.

As presently used, the radiative heating field is recomputed at twelve hour intervals and held constant during the intervening time period. The algorithms account for water vapor, carbon dioxide, ozone and cloudiness. The carbon dioxide concentration distribution is invariant. Between the surface and approximately 300 mb water vapor is obtained from the forecast humidity field. At higher levels, the water vapor distribution is obtained by interpolation between a constant value at 50 mb and the predicted value at 300 mb. The fractional cloud cover is defined from climatological normals in three altitude categories. The cloud field is zonally symmetric and independent of the forecast model's water vapor and temperature fields. Ozone is also specified from climatological fields. The albedo of the underlying surface is set to a climatological background field and is modified to reflect the distribution of snow and ice diagnosed from analysis fields, or in the case of snow from model predictions of precipitation in sufficiently cold air.

2.3 Surface Parameterization

The surface of the earth is allowed to interact with the atmosphere over both land and sea. Over the seas, the sea surface temperature is held invariant at the initial values obtained from near real time analyses of ship and satellite data. An exception is made when sea ice is specified; in which case, the interface temperature is allowed to vary with time in response to energy incident on the ice surface and to energy conducted through the ice from the underlying water. Over land masses, there is a parameterization of the temporal variation of soil and interface temperature in response to incident radiant energy, conduction into the soil and transfer by eddies into the atmosphere.

The important effect of evaporation of water from the soil is parameterized through the use of a soil moisture parameter which initially is specified from climatology but is then allowed to respond to precipitation predicted by the forecast model. Over the seas it is assumed that the interface remains saturated with vapor.

The intensity of the exchange of momentum, latent heat and sensible heat between the air and the underlying surface is governed by a boundary layer parameterization based on the Monin, Obukhov similarity theory. This theory is stretched significantly by our current use of a thick (56 mb), lowest air layer. The intensity of the turbulence in the surface layer is related to wind speed and static stability, in conjunction with a roughness length that is specified to be constant over land. Over the sea the roughness length is an implicit function of the stress acting on the interface.

Water vapor and momentum are also mixed by eddy diffusion. We are using an exchange coefficient that is specified as a function of the vertical wind shear and a linearly varying mixing length that vanishes at 2500 m above the interface.

2.4 Convective Mixing and Precipitation

Vertical mixing of water vapor and sensible heat is allowed throughout the depth of the atmosphere if the temperature lapse rate is greater than dry adiabatic. Cumulus convection is parameterized throughout the depth of the water bearing layers of the model (up to 300 mbs) using Kuo's techniques.

An estimate of convective precipitation is made from the amount of heating produced by the cumulus convection algorithm. This precipitation is accumulated over twelve hourly intervals and made available as a forecast field.

Precipitation is also forecast by accounting for the condensation of water vapor when the specific humidity variable is predicted to exceed its saturation value. Some of this "large scale" precipitation is allowed to evaporate when it falls through drier layers. The amount reaching the ground is also accumulated over twelve hour intervals and made available as a predicted field.

2.5 Lateral Mixing and Time Filter

To maintain reasonably smooth predicted fields lateral diffusion and weak time filters are used in the model. The lateral diffusion is applied to all predicted fields except surface pressure. The parameterization is done in the spectral domain by damping the amplitude of the waves proportionally to the fourth power of the total wave number.

The time integration is done using centered implicit methods for the divergence, temperature and surface pressure, and by centered explicit methods for vorticity and specific humidity. A weak time filter is therefore applied at each time step to avoid the development of a temporal computational mode.

2.6 Analysis and Initialization

Each day of the week the MRF model is used to make a ten day forecast based on the state of the atmosphere at midnight Greenwich Mean Time (GMT). The model is started at about 0600 GMT by performing an analysis of observational data valid in a six hour wide window centered on midnight Greenwich. The first guess for the analysis is provided by the data assimilation system described by Dey and Morone (1985).

The analysis fields are interpolated into the MRF's model coordinate system and transformed as appropriate into spectral coefficient form. This process is sometimes referred to as initialization but it must be distinguished from the process by which the model data is adjusted to avoid the excitation of high frequency oscillations.

The suppression of high frequency oscillations is obtained by using a technique called non-linear normal model initialization. The four gravest gravitational modes are modified by this process to insure that rapid oscillations are not set up initially.

To counteract the tendency for the initialization process to suppress diabatically forced circulations that have significant projections on the model's high frequency, free "gravitational modes", the method has been modified to incorporate the forcing fields associated with diabatic processes. The appropriate forcing is diagnosed by first integrating the uninitialized model forward for two hours of simulated time. The diabatic forcing computed during that time interval is saved and used in a diabatic, non-linear normal mode initialization which preceeds the long-term integration of the model.

3. Comparative Forecast-Skill

3.1 Statistical

During February and March 1985, the new global, medium-range forecast (MRF) model was run once each day and verified in comparison with the then operational forecast model.

The most widely used statistic for assessing the skill of medium-range forecasts is the anomaly correlation coefficient. This statistic is calculated by subtracting the climatological value of the field being verified from both the forecast and observed value of the field. The residuals, or forecast anomaly and observed anomaly, defined on a grid point array over some space domain are then subjected to a computation of their correlation. While any positive correlation suggests that the forecast is superior to climatology, practical interpretation of skill indicates that the correlation will exceed the 0.5 to 0.6 level when the day-by-day evolution of the forecast is interpreted as useful by experienced synoptic meteorologists.

In Figures 2a and 2b the anomaly correlation obtained in the two month period, February-March 1985, for the new MRF model is shown in comparison with the score for the operational model at both 1000 and 500 mbs. The score was calculated for the northern hemisphere, north of 20°N latitude, using the operational analysis to define the observed anomally.

The forecast improvement is evident after two days. Both models show skill well above climatology throughout 10 days; the 60% level of correlation is surpassed by the MRF model through five days, about one day more than the operational model.

3.2 Synoptic

An interesting case, run during January 1985, contrasts the treatment of a North Atlantic block by the MRF and operational models. Figure 3 shows the 500 mb height field observed on January 1 and January 6, 1985. During this 5 day period the split flow over the Atlantic is enhanced by the retrogression to northwestern Europe of the low initially over northern Russia. Figure 4 shows that the operational model predicted too much retrogression of the block whereas the new MRF model provided a significantly more accurate prediction.

3.3 Systematic Errors

The new MRF model parameterizes many physical processes that in nature often tend to nearly cancel each other. In its present stage of development, the model's physical parameterizations do not reflect the near-balances sufficiently well and consequently systematic errors occur.

In Figure 5, the average error in zonal mean temperature in the 10-day forecasts for June 1985 is shown. This serves to illustrate a typical systematic error. We observe strong erroneous cooling near 150 mb at all latitudes and, in the tropics, near 850 mb. Warming near 1000 mb is noted between 80N and 60S. The near-surface warm bias is fully established within the first twelve hours of the forecast; the cold bias grows gradually.

The cooling prevalent away from the surface implies that in the MRF model radiative cooling is not compensated adequately by moist convection and sensible heat transport. The cold bias at 850 mb between 30°N and 30°S occurs at the level of radiative cooling atop shallow clouds and may be linked to the current use of climatological zonally-averaged cloudiness everywhere in the MRF model. The cooling near the tropical tropopause may largely reflect the absence of humidity and latent heat release above 300 mb in the current MRF.

4. Summary

We have provided in this note an overview of the new NMC medium range forecast model and its performance. Work directed toward effecting further enhancements in the formulation of the parameterizations of physical processes is continuing, so that a detailed description of the model is not at present appropriate. We may note further that a development effort is now being made to incorporate this new prediction model into the global data assimilation system used at NMC.

5. Acknowledgements

J. G. Sela led the development of the new model. The support provided to the development of the MRF model by K. Puri, K. Miyakoda, W. Stern, S. Fels, M. D. Schwarzkopf, J. Sirutis is gratefully acknowledged. Important contributions to the developmental testing of the new model were made by many NMC staff members, most notably, K. Campana, W. Facey, A. J. Desmarais, P. Caplan, M. S. Tracton, M. J. Rozwodoski, F. Hughes, and W. Collins. Special thanks are due to F. Mesinger who provided excellent counsel on the state of the science of medium range forecasting. Finally, we acknowledge the managerial support and direction of W. D. Bonner, and J. A. Brown, who set high goals but also the resources to achieve them.

CAPTIONS FOR FIGURES

Figure 1. Example of change in orogrpahic field (a) mean mountains (b) silhouette mountains.

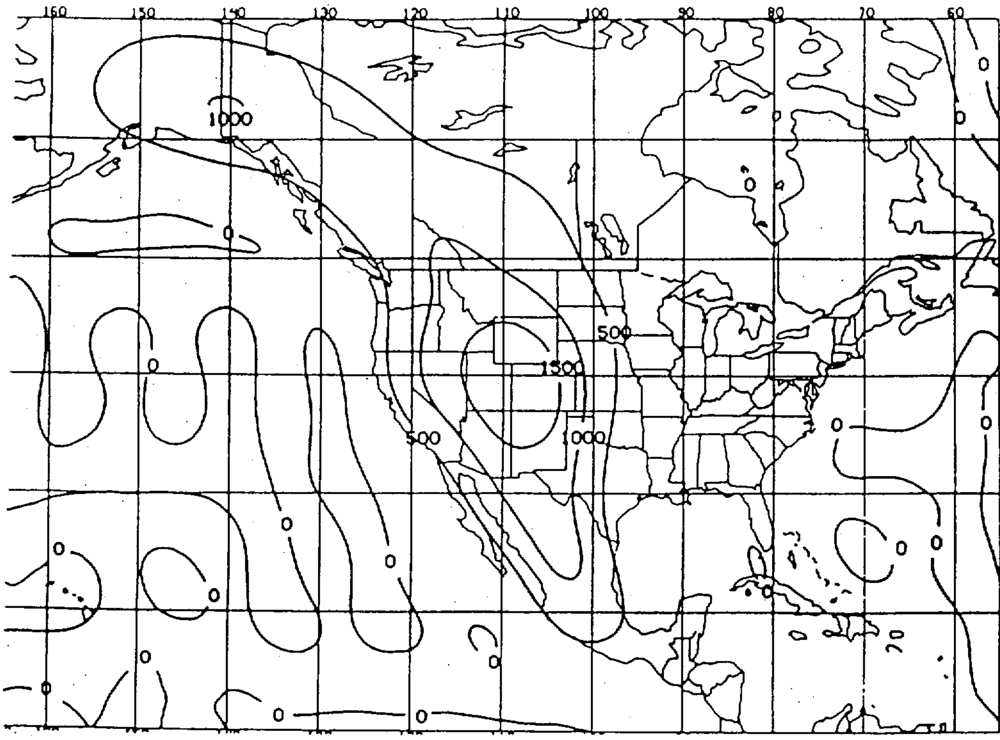
Figure 2. Anomal correlation score for comparsion of older global model (solid line) and new MRF model (asterisks) based on forecasts during February and March 1985. (a) for 1000 mb; and (b) for 500 mb. Abscissa shows length of forecast in days.

Figure 3. Analyses of observed 500-mb height for 0000 GMT 1 January 1985 (a), 6 January 1985 (b).

Figure 4. Forecast of 500-mb height valid for 0000 GMT 6 January 1985. (a) older operational model; (b) new MRF model.

Figure 5. The monthly mean error in zonal mean temperature in 10-day forecasts for June 1985. Contour interval 1°C.

OLD MEAN MTS



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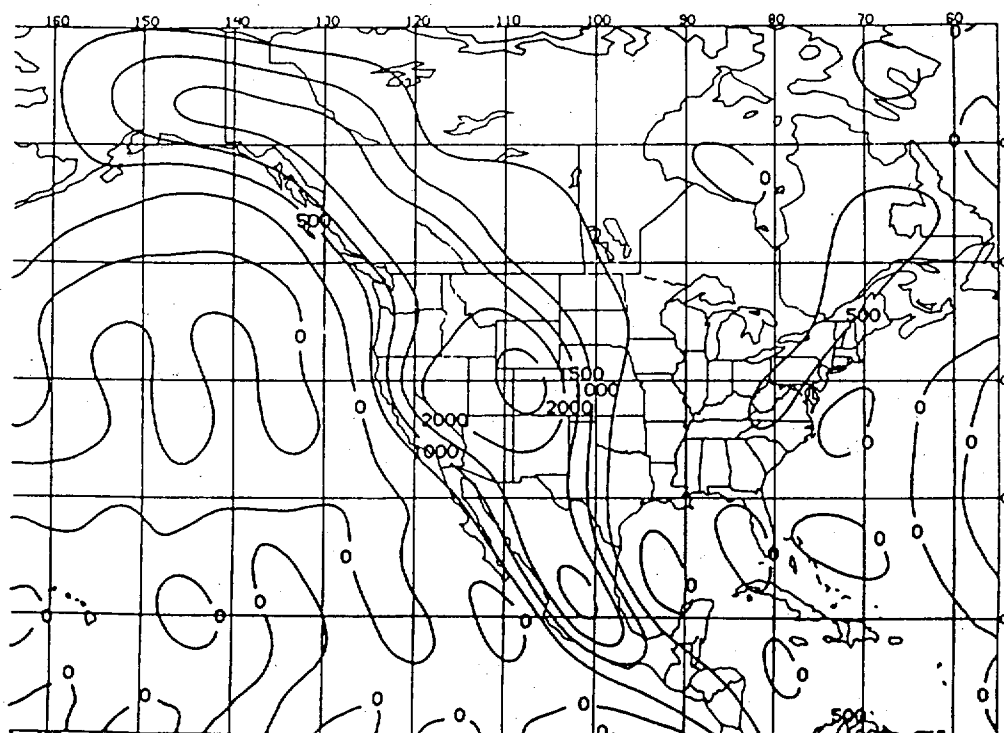

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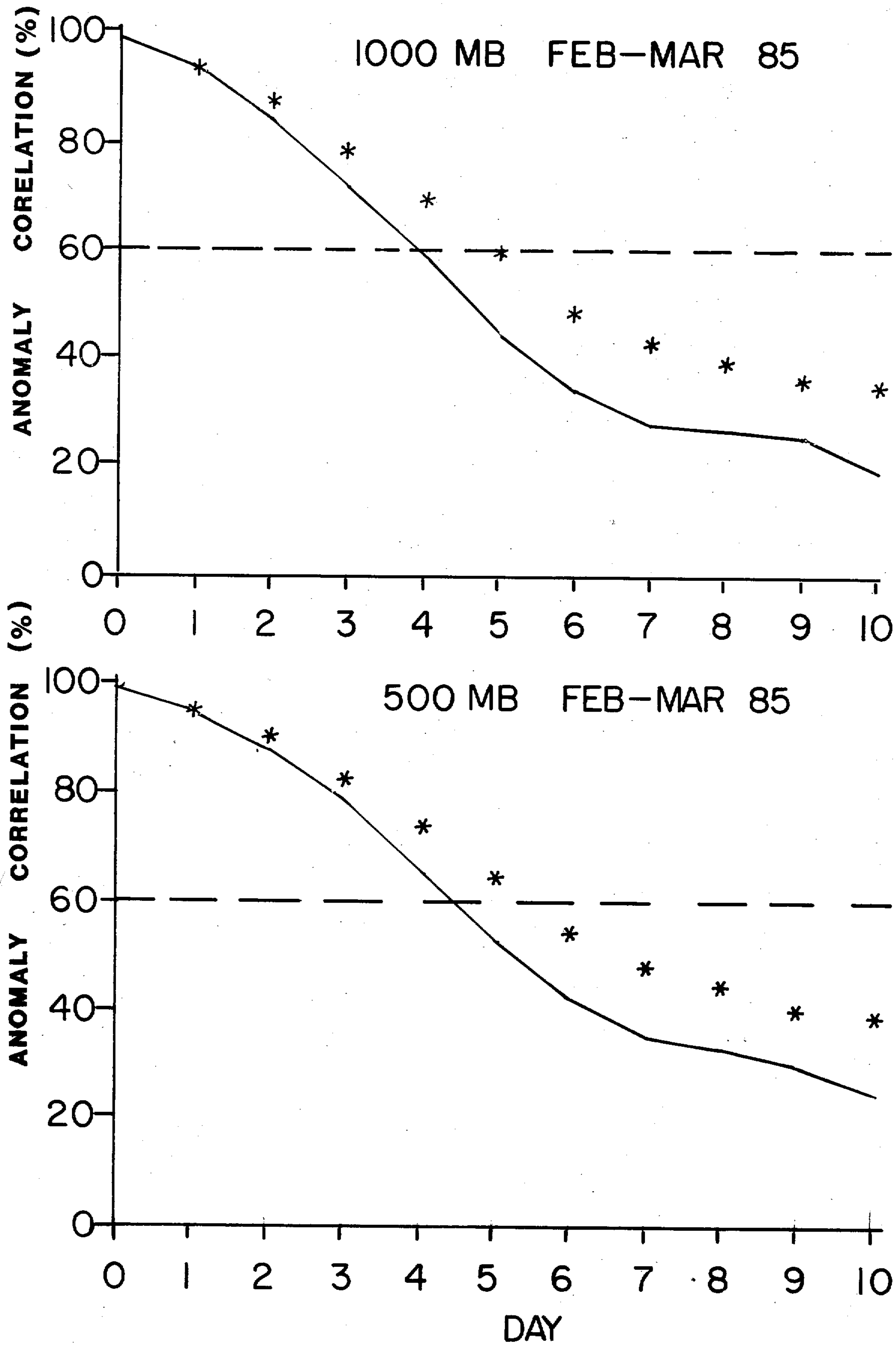
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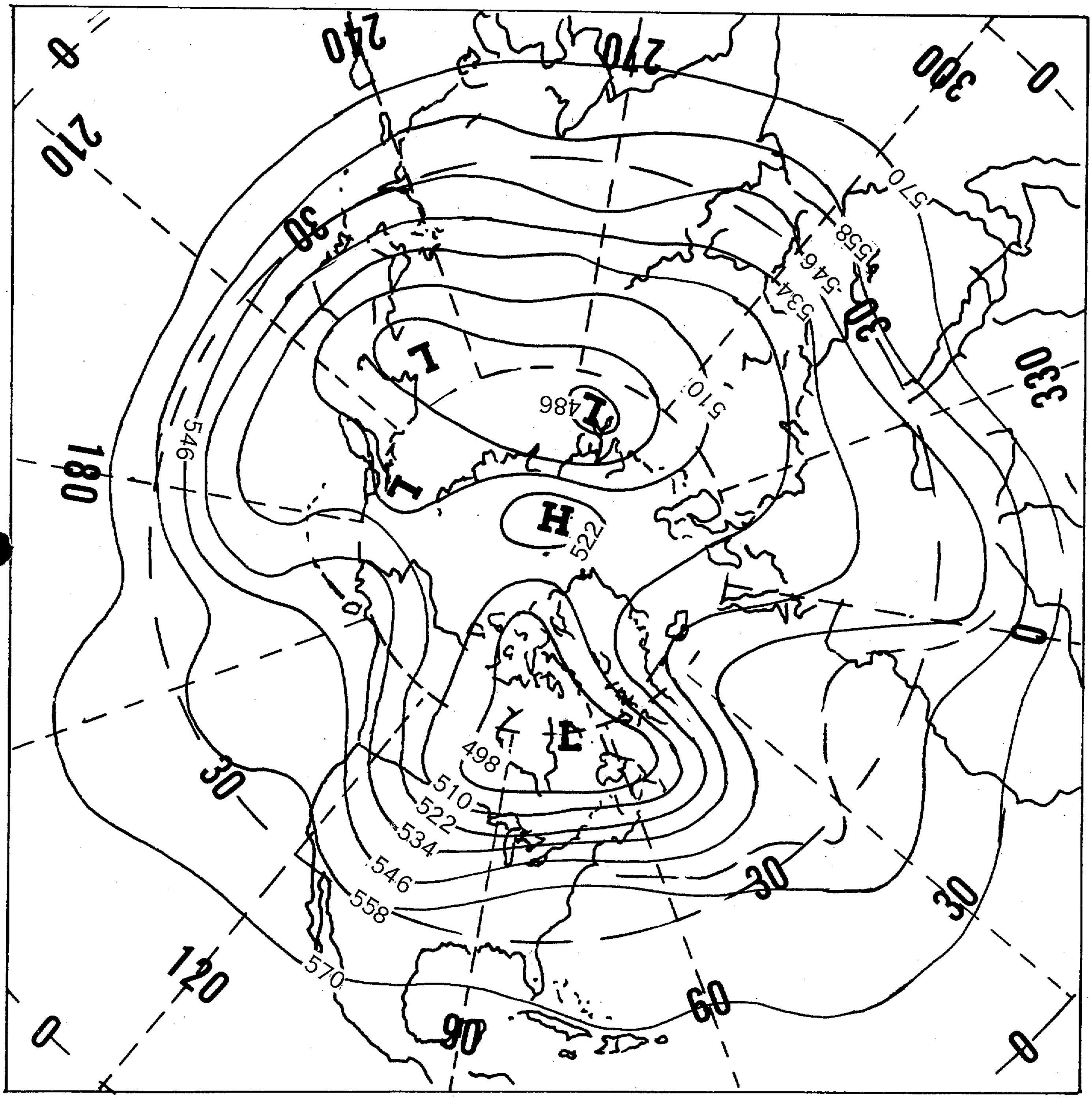

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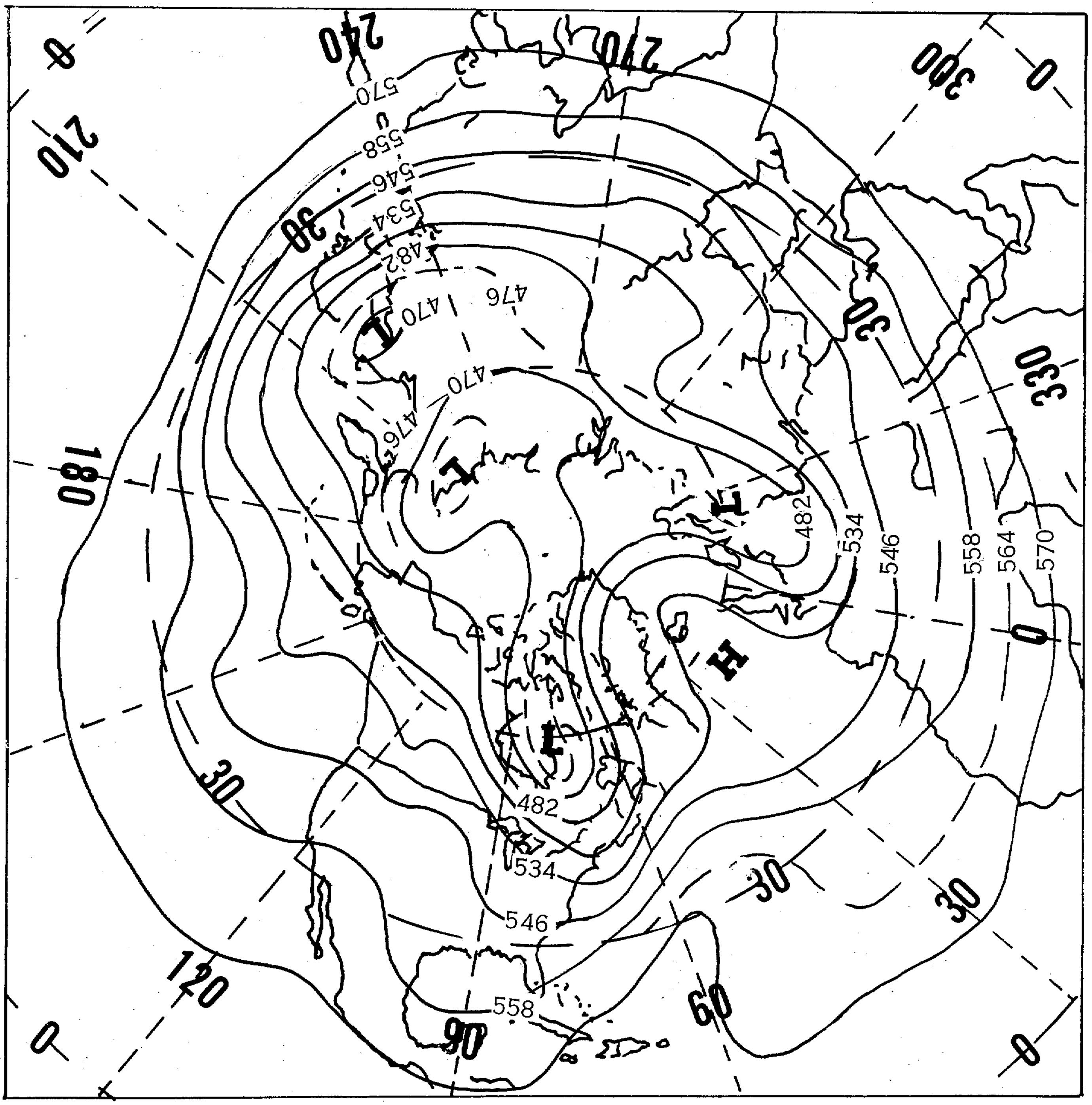
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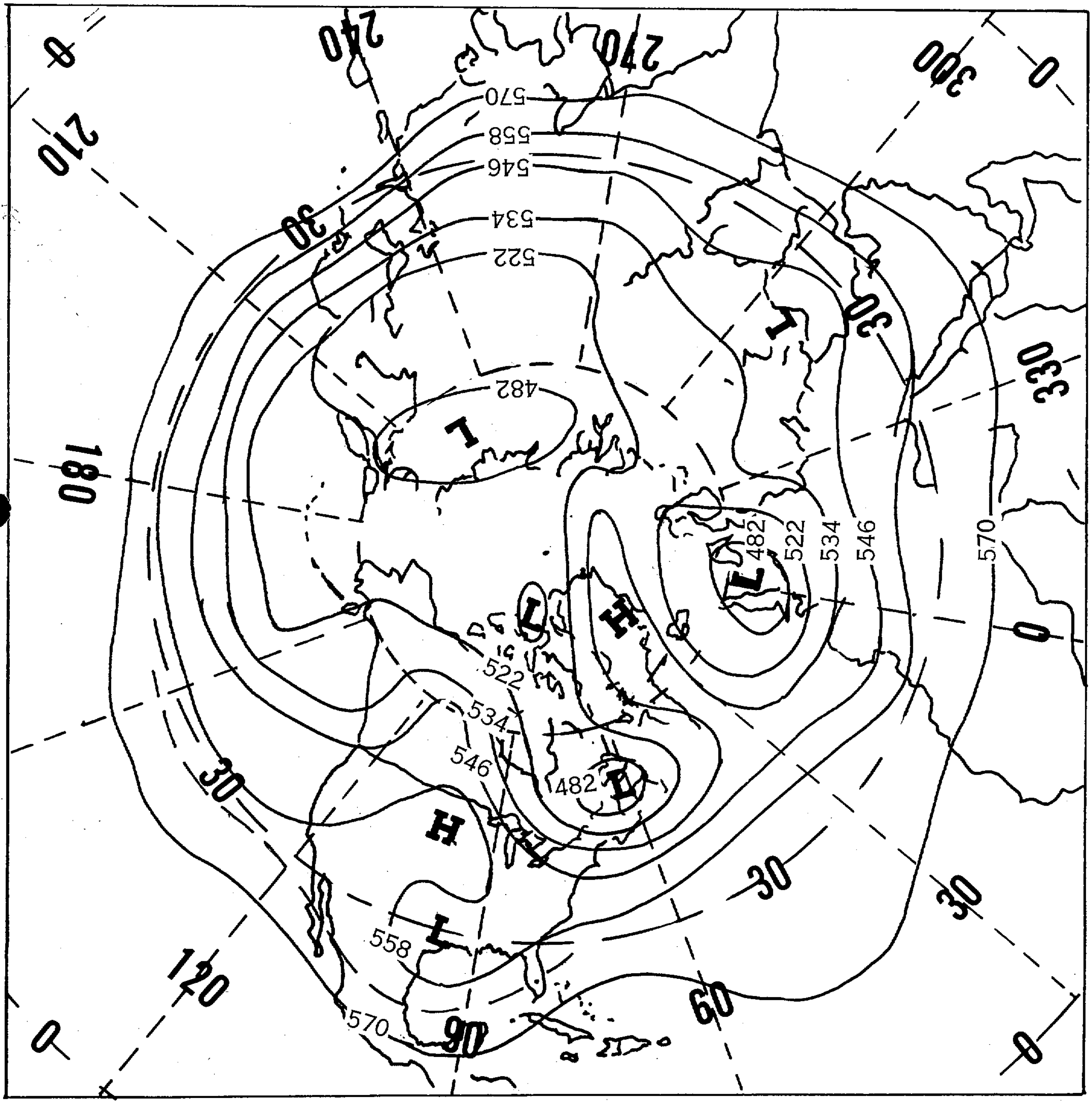

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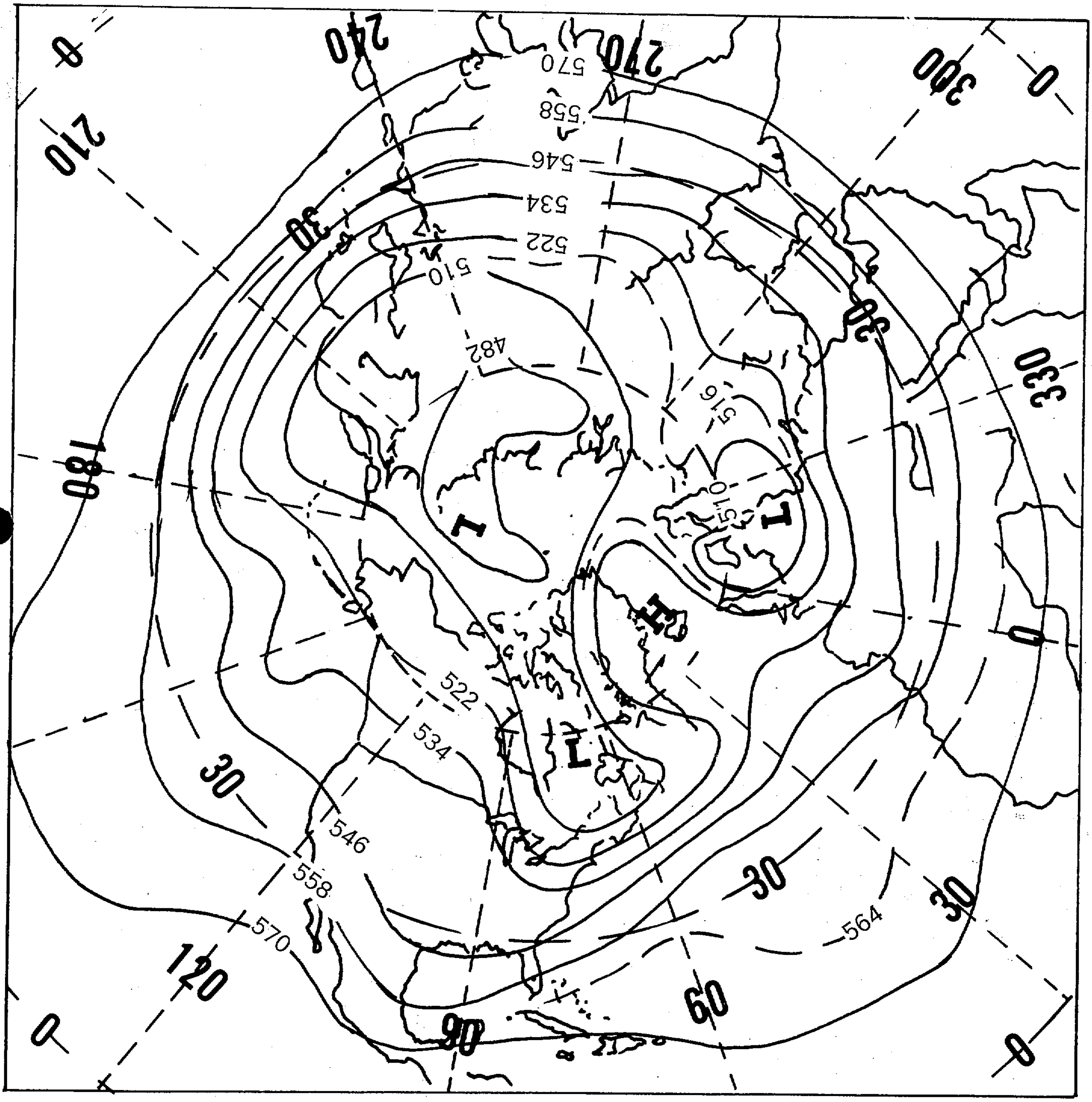
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